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CONDITIONED EYELID REACTIONS TO A LIGHT STIMULUS BASED ON THE REFLEX WINK TO SOUND

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FOREWORD

In this experimental investigation of the conditioning process, the eyelid reaction was selected because it involves a very light and mobile bodily member lending itself to a study of the controls which operate in the intact individual affecting relatively simple muscular activity. Involuntary blinking occurs more or less throughout the waking hours, and there is some measure of deliberate or voluntary control over the eyelid in opening or closing the eye. This interplay of reflex and voluntary action points to a probable significance of the eyelid reaction in an experimental program dealing with the modifiability of human behavior.

For constant helpfulness in the formulation of the experimental procedure and throughout the investigation, I am deeply indebted to Prof. Raymond Dodge. The apparatus and techniques employed are largely those which he developed during his many years of research on reflexes and the problems of human variability.

At many points there have been suggestions and criticisms from Prof. Roswell P. Angier and other members of the Department of Psychology and the Section of Psychology in the Institute of Human Relations. To these friends and teachers I am deeply grateful.

ERNEST R. HILGARD

Yale University,
February, 1931.

CONTENTS

I. Previous Studies of Conditioned Eyelid Reactions

In the experiments to be reported,[1] conditioned eyelid reactions to an illumination change were formed by repeatedly pairing the visual stimulus with a loud sound which served as the adequate or unconditioned stimulus for a reflex wink. Conditioned eyelid reactions have been previously reported by Cason, Dodge and Switzer.

Cason (4) utilized electrical stimulation of the skin of the face as the unconditioned stimulus for a wink. The conditioned stimulus was either the click of a telegraph relay or sounder. The sound-shock combination was presented simultaneously a number of times, after which the sound alone evoked a response. Conditioned reactions were reported from eight subjects. Recording was by means of the make of an electrical circuit at a given phase of lid closure, the reaction-time being measured by a Bergstrom chronoscope. The chief quantitative conclusion of Cason's experiment has to do with the reaction-time of the conditioned response as compared with that of the voluntary wink to sound. With the exception of one subject, the conditioned reaction was of reliably shorter average reaction-time than the voluntary reaction. The value of the findings is decreased, however, by the method of recording and by the method of treating the data. The timing gave no indication of the course of lid motion. Small winks were not registered at all and delays due to the phase of lid motion at which contact was made, as well as instrumental latencies, gave reaction-times at least 50σ too long, according to Cason (5). In calculating the average reaction-time of conditioned reactions there were included times as short as 40σ, which reactions, in view of the instrumental delays, must have anticipated the stimuli. They cannot legitimately be considered as reactions to the conditioned stimulus. Cason points out that the lower limit to be expected for the conditioned reaction-time is the shortest time obtained with the sound-shock combination

[1] This study is rewritten from a dissertation presented to the faculty of the graduate school of Yale University in partial fulfillment of the requirements for the degree of Doctor of Philosophy in psychology, 1930.

(4, p. 182). Yet for every one of the six subjects for whom the detailed data are given, there are included reaction-times lower than this shortest time. For two subjects (E. B. and E. G.), the lower *quartile* of conditioned reaction-times is below this "expected lower limit." No such anticipatory reactions were included in the voluntary reaction-times. Hence there is a greater difference in mean reaction-times between the conditioned and voluntary responses than is justified. The evidence that the conditioned reaction is too rapid to be within the range of traditional reaction-time measures is inconclusive.

Dodge (12) tells little about the conditioning he obtained except to say that it proved possible to produce a lid reflex of approximately normal latency by a knee-jerk stimulus after a considerable number of simultaneous excitations.[2]

Switzer (38) employed an electrically released hammer striking the face below the eye as the unconditioned stimulus to winking. As the conditioned stimulus he used an electric buzzer which was always sounded after the unconditioned stimulus. The lid reactions were recorded by means of a thread attached to the eyelid and activating a glass needle marking on a kymograph. Backward conditioning was secured in 18 out of 20 subjects in his experimental group, the reactions being formed most readily when the conditioned stimulus followed the unconditioned stimulus by 0.5 to 1 second. The amplitude of the conditioned responses was from one-third to one-half that of the unconditioned response. Curves of experimental extinction are given showing the decrement in response as the conditioned stimulus was successively repeated alone. The curves are characterized by an initial rise and fairly rapid fall.

Switzer's study does not deal with the latency of the reactions obtained; Cason's neglected amplitude. The present investigation is a further exploration of the conditioned eyelid reaction in which both latency and amplitude are measured. The experiments concerned the possibility of conditioning the lid reflex to light.

[2] In another place he adds: "but that may have been due to a faint noise of the blow on the tendon" (14).

II. Apparatus

For accurate study of the conditioning process, an instrument was desirable which would not only accurately control the time interval between the conditioned and unconditioned stimuli but would also record the course of lid motion in its time relations to these stimuli. Such an instrument was available in the Dodge pendulum-photochronograph, the use of which for the purpose of recording eyelid reactions has already been described in the literature (11). Its great accuracy and convenience are enhanced for the purposes of conditioned reflex investigation by its noiselessness of operation. The experimental set-up included the following functional units:

1. Pendulum-photochronograph. A pendulum in the course of its swing released the stimuli at desired intervals and carried the sensitive paper on which the stimuli and responses were photographically registered.

2. Primary light source. A 100 c.p. Ediswan Point-o-lite provided a point source of light which produced the shadows by which photographic registration was made.

3. Cylindrical lens and grid of threads. The lens focussed the light to a vertical line on the photographic paper. The shadow of the grid of silk threads across the lens produced a series of lines 1 mm. apart on the record. These functioned as abscissae and served as guide lines for measuring the extent of lid motion.

4. Timing device. A toothed wheel carried by the armature of a motor run synchronously with an electrically driven 100 d.v. tuning fork interrupted the light source every 5σ, producing time lines as ordinates on the record. Every tenth tooth was emphasized, accentuating ordinates every 50σ. The shadows of the threads and the time lines together gave a cross-sectioned appearance to the records, greatly facilitating their reading.

5. Artificial lash. An artificial eyelash of paper 1.5 mm. by 20 mm. was attached by a drop of gum arabic just above the

natural lashes and cast a shadow across the lens which gave an accurate record of the slightest lid motion. Since only relative values of amplitude were required, the extent of response is reported in terms of millimeters of lid motion as read from the records. The magnification is three to four times the lid motion at the eyeball, the magnification increasing somewhat at the greater amplitudes.

6. Fixation object. The fixation object was a dimly illuminated cross 1.5 cm. by 1.5 cm., the arms being 2 mm. wide, viewed binocularly from a distance of 170 cm.

7. Head rest. The head was maintained in position both for fixating the cross and for holding the artificial eyelash in the beam of recording light. The subject was seated, leaning forward with arms supported. A wooden tongue depressor was used as a mouth rest and the forehead rested against a support padded with paper tissue.

8. Sound stimulus. A mouse-trap type of wire hammer was magnetically released and produced the sound stimulus as it struck a wooden box resonator. Recording was by means of the shadow of a direct lever off-set from the resonator. The sharp snap is an effective, unconditioned stimulus for eliciting a reflex wink. The reflex was small for some subjects, but it was found for all of those tested.

9. Light stimulus. Surrounding the fixation object was a reflecting surface of sanded tin 10 cm. by 15 cm. on which the illumination change occurred. This illumination increase which constituted the light stimulus was produced by the release of a magnetically controlled pendulum shutter, swinging before the filament of a 150 watt incandescent lamp 185 cm. from the screen. As the shutter was released, the light was reflected from the sanded tin to the eyes of the subject. The moment of stimulation was directly recorded by deflecting a portion of the stimulus light to the cylindrical lens and photographic paper. Rough photometric measurement showed the tin surface to have an apparent brightness of 0.1 meter-candle before the stimulus occurred. After the release of the shutter, the apparent brightness value increased to from 30 to 50 meter-candles on the

several portions of the surface. This illumination change, while clearly perceptible, called forth none or only minimal unconditioned responses from most subjects.

Sample records are presented in Figure 1, p. 10, and in Figure 7, p. 27. An inspection of the lid reaction line shows that while it is difficult to determine the exact moment when the several responses begin, the slightest departure from the baseline is noticeable on the records.

III. Experimental Procedure and Controls

1. Instructions to the subject

The paper lash was attached to the left eyelid of the subject [3] and he was seated in position. After the chair, forehead rest, mouth rest and fixation windows were adjusted so that the subject could comfortably take the position which permitted him to view the fixation object clearly and placed the shadow of the lash at the proper height across the lens, he was ready to receive the instructions.

"You are now in position to observe the fixation cross. Continue in that position until told to sit back and rest. You may close your eyes at will; under no circumstances allow them to become strained. Be sure to report any discomfort."

During preliminary exploration, the experimenter presented the stimuli at any time when the subject's eyes were seen to be open. While all the major phenomena appeared under these conditions, there were many equivocal and confusing records because of stimulation occurring just after a wink or while one was under way. In order to secure greater uniformity, further instructions were subsequently employed following Dodge's procedure:

"I shall give you commands with regard to your breathing as follows: 'inhale—exhale—inhale—hold.' When I say 'hold' you will hold your breath and look steadily at the fixation cross until after stimulation has occurred. Try following my commands." Here the words "inhale—exhale—inhale" were repeated spaced at intervals of 2 seconds. The word "hold" followed the word "inhale" by 1 second. The breathing commands were repeated for practice until the subject could comfortably pick up the rhythm. He was then further instructed with regard to the stimuli before the experiment began.

[3] Of the subjects whose reactions are treated, Subject A was a graduate student in philosophy, Subjects C, D, E, F, G, and H, graduate students in psychology, Subject I, an advanced undergraduate. All but Subject E were male.

"The only stimuli which will be presented are a sound and an illumination change around the fixation cross. You may disregard the stimuli, attempting neither to wink nor to inhibit winking. Pay particular attention to following the breathing instructions and while your breath is held, gaze steadily at the cross."

Comparable results were found with the breathing instructions and without, except for the greater uniformity under the conditions of controlled breathing.

2. Sequences of Stimuli

The stimuli (light and sound) were presented, alone or in pairs, twelve times in each experimental period at intervals of 30 seconds. A 2-minute rest followed successive periods of twelve presentations. As a rule, four such periods (48 records) constituted a session for the subject, a session lasting thirty minutes.

The most frequently employed sequence was as follows:

First session with the subject

6 reactions to the light stimulus alone
36 reactions to the sound stimulus alone
6 reactions to the light stimulus alone

48 reactions (total)

Second session (and succeeding sessions)

6 reactions to the light stimulus alone
36 reactions to the paired light and sound stimuli [4]
6 reactions to the light stimulus alone

48 reactions (total)

The first session provided norms for the reactions to light and sound present from the beginning and for the negative adaptation of the reflex to sound within the series. If the dis-

[4] In later experiments the light stimulus was omitted from six of these reactions, selected in random order. The reactions to sound alone in the midst of a conditioning series gave evidence of the alterations of the unconditioned reaction during the conditioning process.

turbance by the loud sound stimulus had increased the tendency to wink to light, this should have been revealed in the later reactions to light. During any one conditioning experiment which usually covered at least two daily sessions, the interval between the light stimulus and the sound stimulus remained constant, the intervals employed ranging from simultaneity to 400σ.

3. Experimental controls

There seems to be little point in recapitulating the many sources of variability which are operative in a psychological experiment.[5] The experimental setting is far from a simple stimulus-response situation. However, it is important to know as accurately as possible what environmental changes were concomitant with the changes photographically recorded.

Care was taken in the setting of the stimuli before each trial that cues should not be given which would suggest the nature of the stimuli about to be presented. Both stimuli were always set before each trial, but either the sound or light could be withheld by short-circuiting or mechanically. Within the possible combinations, the subject could not judge from the sounds incidental to the setting of the switches which stimuli were later to be presented.

There were no clicks or scraping of any kind involved in the release of the pendulum. Control records obtained during trials in which the pendulum was released but no stimuli presented showed occasional halting responses coming late on the record, after the breath had been held for some time, but not a single response was obtained which would be confused either in time relations or course of lid motion with other reactions in the

[5] Dodge has given one such list: "Psycho-physiological tradition includes a long list of known conditions of variability of reaction to similar stimuli. The most conspicuous may be enumerated as follows: changes in set, incentive and emotional reinforcement; suggestion and expectation, anticipatory reaction; learning and forgetting; adaptation and resystematization; conditioning and extinction; the refractory phase and rebound; Bahnung and facilitation; relative fatigue and exhaustion; warming up and recovery; co-contraction and reciprocal relaxation of antagonistic muscle groups; drugs and internal secretions; sleep and somatic rhythms; the interaction of delay paths; age and physical condition" (**15**).

series. Subjective report and objective record agreed on the silence of the pendulum and its electrical contacts.

The latency of the release mechanism of the sound hammer introduced a potential source of error. Some 50σ elapsed between the break of the circuit through the magnets of the sound control and the impact of the sound hammer on the resonator. It was that impact which was registered on the record as the moment of stimulation. There were slight sounds during the release period, but the records showed that they were not reacted to under ordinary reflex conditions.[6]

The absence of significant secondary cues in the light shutter release mechanism was adequately tested through the use of a secondary shutter which could be interposed between the light and the reflecting screen, preventing the appearance of the light stimulus when the main shutter was released. The light alone before conditioning evoked only occasional minimal responses; the light shutter alone did not evoke even these minimal responses. The light alone after conditioning called forth larger responses; the light shutter release elicited none. There is no doubt that the reaction was to the light in both cases and not to secondary cues.

The shadow method of registration of the lid response is very accurate and responses were frequently recorded when the subject reported that no response occurred. The fact that the record gave a continuous picture of the lid movements from a period of time preceding stimulation beyond the time of the return of the lid shadow to the normal position prevented there being any important factor in the response which was not, sooner or later, revealed on the record.

[6] In some preliminary exploration involving voluntary reactions to the sound stimulus, the preliminary cues resulted in very short reaction-times.

IV. Conditioned Eyelid Reactions as Recorded from Five Subjects

A simplified pictorial story of the conditioning process is given in Figure 1, which consists of a reproduction of six records of the reactions of Subject F, five of which were selected from one day's experimental session. Considered in order, these records reveal the following stages in the conditioning process:

1. Response to light is absent (or minimal[7]) in the early presentations of light alone.

2. The unconditioned reflex wink to sound is regularly present from the start. This record is taken from a preliminary session with the subject; all others are from the fourth conditioning period.

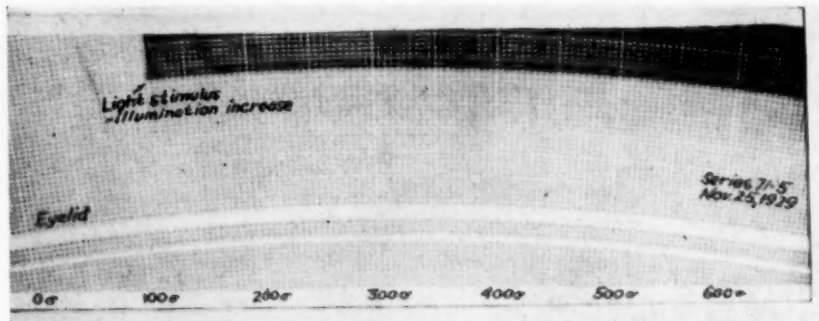
3. The record obtained during the early training period, when the light is first paired with sound, shows no evidence of reaction to the light; the unconditioned reaction to the sound stimulus is present following the light by 290σ.

4. After repeating the paired stimuli, the conditioned response to light appears as the first component of a dual or dicrotic reaction, the second peak of which is the unconditioned reflex to sound. This first component anticipates the sound stimulus and follows the light stimulus (in the record illustrated) by 195σ.

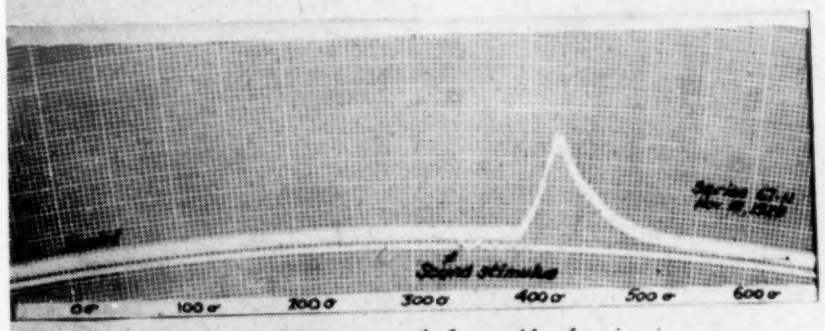
5. When the light is later presented alone, the conditioned response appears as a reaction homologous with the first component of the dual response in the preceding record. In the record illustrated, the reaction-time to light of the conditioned reaction is 210σ.

6. If the light stimulus is presented alone a number of times, there is a tendency for the conditioned reaction to disappear, or, to use Pavlov's term, to be extinguished.

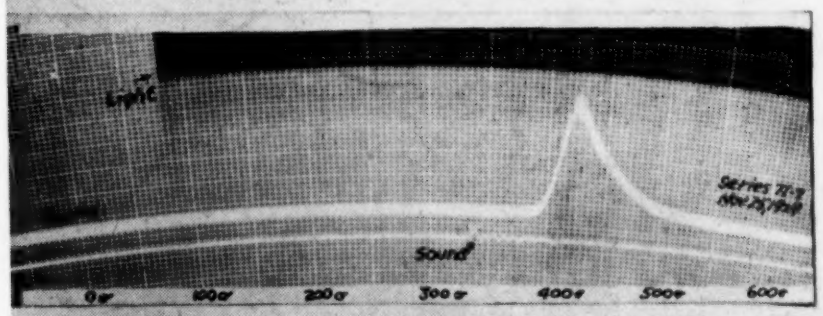
[7] A minimal unconditioned lid reaction to light which cannot be detected in the reproduced records was occasionally legible for this subject at a latency averaging 117σ in 48 measured reactions. The average amplitude of these responses was but 0.6 mm. on the record. These unconditioned reflexes to light are not to be confused with the conditioned reactions of longer latency which develop during the conditioning series.



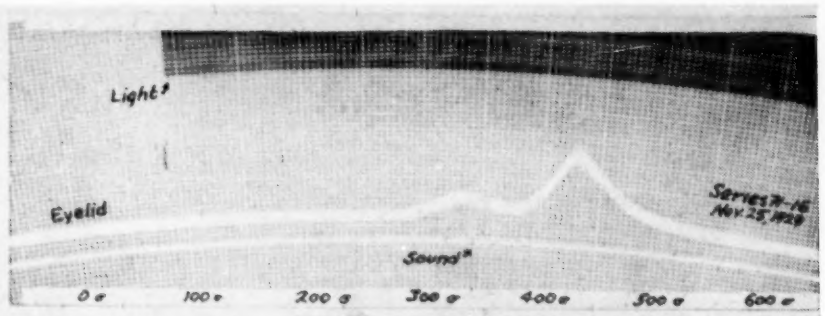
(1) There is at first no response to the light stimulus



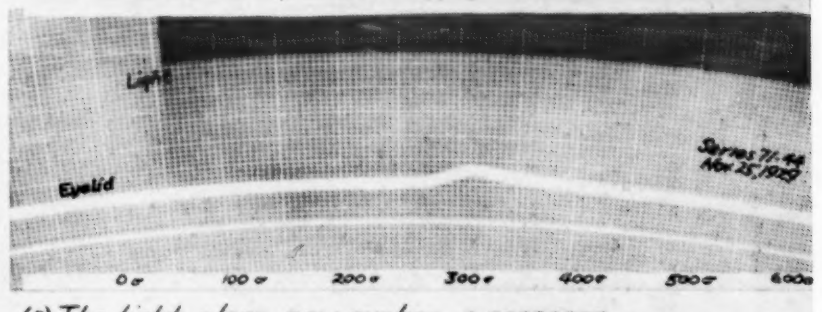
(2) A reflex to sound is present from the beginning



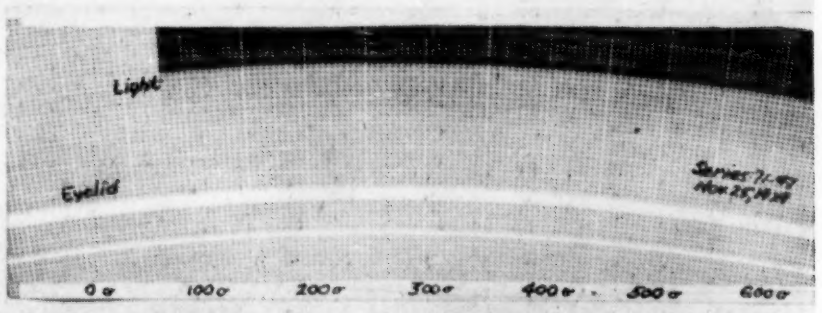
(3) The light precedes sound by 250σ. The reflex follows sound



(4) The conditioned response to light appears upon repetition



(5) The light alone now evokes a response



(6) The response is extinguished through repetition of light alone

FIGURE 1. SPECIMEN RECORDS OF THE CONDITIONING PROCESS

While there are a number of qualifications which must be made with regard to this scheme, the major features of the process are revealed in these specimen records.

Similar conditioned reactions were obtained from four other subjects (Subjects D, E, G, I), the conditioned response appearing as the initial component of a dual reaction, the second component of which was, as in record 4 of Figure 1, the unconditioned reaction to sound.[8]

Because of the appearance of the conditioned reaction during the training series as a response anticipatory to the reinforcing stimulus, it is possible to trace the development of the conditioned reaction from its initial appearance, trial by trial. This method has obvious advantages over tracing the course of development of the reaction by testing from time to time with the conditioned stimulus alone, since there is no way of telling without adequate successive records when the reaction first appears, and premature testing with the conditioned stimulus may delay the appearance of the conditioned reaction, while every test after appearance results in some extinction. The present type of record which shows the status of the conditioned reaction throughout the training series makes possible a genuine learning curve for conditioned reactions.[9]

[8] Of the three further subjects, two (Subjects C and H) had very small unconditioned reflexes to sound. Conditioned reactions were not obtained in their cases. One subject (Subject A) gave unusually large reflexes to light from the start, as shown in Figure 7, p. 27. All conditioning in his case was manifested as a variation of this reaction.

[9] The method depends, of course, on the appearance of the conditioned reaction as an initial component of a dual response. That the conditioned response does so appear is true for several reported studies. Freeman presents records of the conditioned galvanic reaction of this type (**16**). Wever's conditioned breathing records from a cat show the reaction to the conditioned stimulus to precede the reaction to the reinforcing stimulus (**45**). Similarly, Upton found for the guinea pig a conditioned response anticipating the unconditioned stimulus. There later developed in addition an end response which appears to him to be a genuine substitute for the reaction to the unconditioned stimulus (**43**). Schlosberg reports in his study of the knee-jerk: "In addition to the actual knee-jerk, there were many indications of conditioning. Chief among these was the tendency to kick before the blow occurred. This happened fairly frequently" (**37**, p. 482 f). Hull, taking instances from Pavlov, reports the "curious tendency, where the conditioned stimulus precedes the unconditioned one in the conditioning process, for the reaction to be attracted toward the former. Under certain circumstances the reaction (after a number of reinforcements) may begin a considerable interval before the delivery of the unconditioned stimulus" (**21**, p. 499). Switzer,

The development of conditioned reactions proceeds both in terms of frequency of reaction and in terms of extent of lid motion. Plotting the extent of the conditioned component in successive reactions to the paired stimuli gives in terms of the raw data a kind of learning curve showing the changes in the reaction with repetition. Such a curve is presented for the reactions of Subject F in Figure 2. Curve A show the development of the conditioned reaction as a component of the dual response when the light and sound were presented paired at an interval of 250σ. Curve B shows the reactions to light presented alone, as tested at the beginning of each daily session and at the end of each session. These curves are in no sense to be considered normative. They are presented simply as showing the methodological possibility of an intimate study of the development of conditioned reactions during successive presentations of the paired stimuli.

Curve A of Figure 2 may be reduced to a more conventional form of learning curve by plotting the daily average frequency or extent. This has been done in Figure 3. The two curves are quite independent, *i.e.*, there is no necessary connection between their forms. The extent of the conditioned reaction does not necessarily increase as the frequency increases. There is, however, a rough correspondence between the two curves (A and B of Figure 3), both of them suggesting positive acceleration at first, which, in the nature of the units, must shortly have become negative acceleration.[10]

with the unconditioned stimulus preceding, found the first evidence of conditioning in double winks, a complete wink to his striker followed by a partial closure to the buzzer (**38**, p. 83).

In each of these examples the conditioned reaction is a *new* reaction which commonly shows up in the training series, without testing, when the conditioned stimulus and unconditioned stimulus are sufficiently separated in time.

[10] Frequency has a maximum at 100 per cent; extent has a maximum at complete closure. Negative acceleration would be expected to set in as the limits were approached. The result would be curves of the S-form, which some believe to be typical of learning curves. The curves reported by Kleitman and Crisler for the conditioned salivary responses of dogs are interpreted as S-curves of this kind. Such curves have been reported for the learning of various materials by human subjects, *e.g.*, typewriting by Chapman and Hills (**7**) and Thurstone (**40**); the evolution of concepts by Hull (**20**). McGeoch (**31**) reconstructing Peterson's data (**34**) finds some positive acceleration for the learning of difficult nonsense syllable lists.

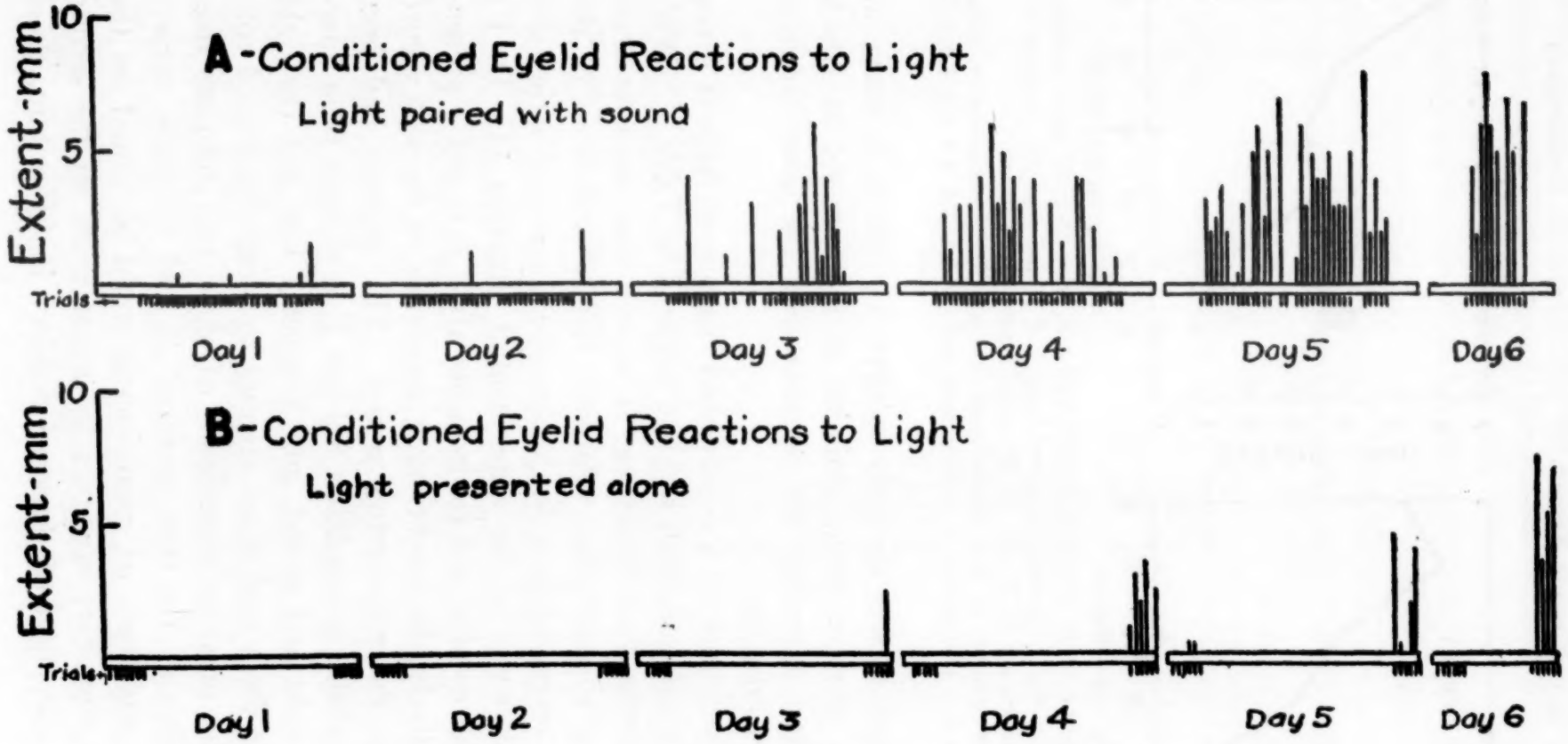
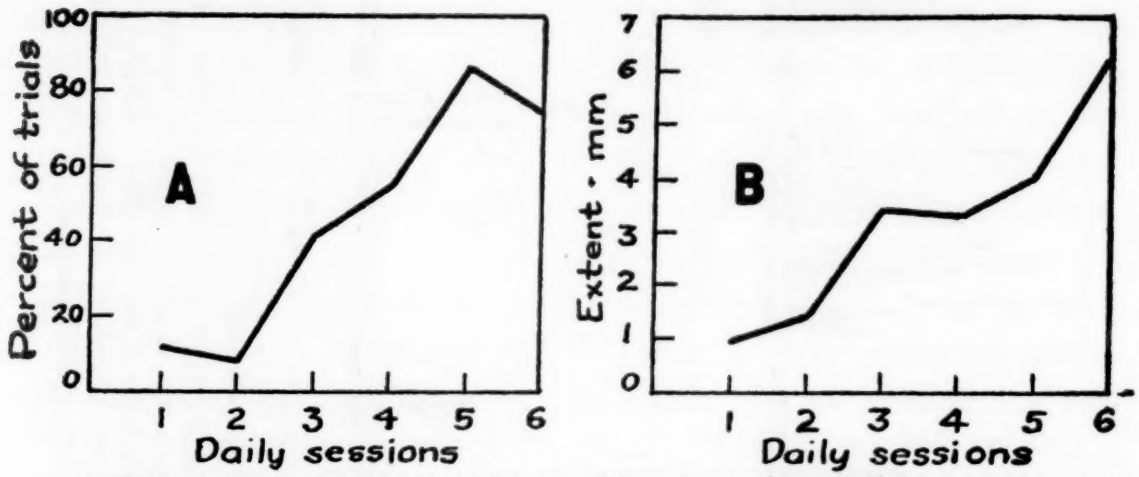


FIGURE. 2. TRIAL BY TRIAL DEVELOPMENT OF CONDITIONED REACTIONS

A. Changes in the extent of conditioned eyelid reactions to light when the light preceded the sound by 250σ. Each small mark below the base-line represents one trial in which the light stimulus was present. The extent of the conditioned reaction, where one occurred, is indicated by a vertical line above the mark which designates the stimulus. Subject F.

B. Changes in the extent of conditioned eyelid reactions to the light presented alone in trials at the beginning and at the end of the daily sessions. The presence of the light stimulus is indicated by marks below the base-line.

FIGURE 3. DAILY AVERAGE FREQUENCY AND EXTENT OF CONDITIONED REACTIONS



A. The per cent of trials in which conditioned reactions to light were present as components of a dual response to paired light and sound stimuli. Subject F. The successive values are 12, 9, 41, 55, 87, and 75 per cent.

B. The average extent of the conditioned components in successive daily sessions. Subject F. The values, in millimeters, are 1.0, 1.4, 3.4, 3.3, 4.3, 4.0, 6.2.

While Subject F was the only subject for whom as many as six successive sessions were available at the interval at which conditioning first appeared, the sessions with the other subjects reveal similar tendencies.

The first appearance of a conditioned reaction to light is given for each of the sessions with the five subjects in Table 1. With the sensitive method of recording, it is seen that the first trace of conditioning appears after relatively few presentations of the stimuli. The three subjects for whom the successful series was their first experience in the experimental situation (G, D, F) showed the first conditioned components after 1, 6 and 7 presentations, respectively, the conditioning appearing on the next record anticipatory to the reinforcing sound. The attempt had been made unsuccessfully to condition Subject E at shorter time intervals between light and sound, and Subject I had had the light presented after the sound in an attempt to secure backward conditioning. The previous experience of these two subjects may have been inhibitory for they required 21 and 19 trials, respectively, before any trace of conditioning could be found on the records. The responses appeared in earlier trials on the second day with the exception of those of Subject F. For him, there

were required 13 presentations on the second day before a conditioned response occurred, but it came earlier on the four succeeding days, although on all but one day at least one paired presentation was required before the reaction made its appearance.

TABLE 1

First Appearance of Conditioned Reactions to Light in Each Session with Five Subjects

Subject	Interval by which Light preceded Sound	Session	Number of paired Light-Sound presentations before first conditioned reaction appeared
G	400σ	Day 1	1
		Day 2	0
D	300σ	Day 1	6
		Day 2	0
		Day 3	1
		Day 4	0
E	300σ	Day 1	21
		Day 2	6
F	250σ	Day 1	7
		Day 2	13
		Day 3	4
		Day 4	2
		Day 5	0
		Day 6	1
I	200σ	Day 1	19
		Day 2	2

Subjects E and I had previous experience in the experimental setting, at intervals between the light and sound unfavorable for the appearance of conditioned reactions. For subjects G, D, and F, these series constituted the initial participation in the experiment.

Once having occurred, the conditioned reaction was by no means regularly present thereafter, although there is a tendency for the relative frequency to increase as the paired presentations are continued, as was evident from Figure 2. Even well along in a series there are occasional records in which there is no trace of conditioned response to light. The number of conditioned reactions present, and the percentage of trials with the paired stimuli in which they were found, are given in Table 2.

The rate of conditioning depends on the interval between light and sound in successive presentations, on the rate and number of such presentations, on the susceptibility of the subjects to the chosen stimuli. Individual differences revealed in the reactions

of the present subjects are evident from Table 3, which gives the average amplitudes of the reactions to light and sound throughout the sessions as reported. For the most part, the conditioned reactions to light tend to be smaller than the unconditioned reactions to sound, although this is not an invariable rule.

The latency of the reactions to light and sound also show individual differences. The average reaction-times are given in Table 4. The mean latency of the reflex to sound varies from 28.0σ to 48.8σ in the reactions studied. The latency is but little

TABLE 2

Frequency of Conditioned Components in Lid Reactions to Light and Sound in Each Session with Five Subjects

Subject	Interval by which Light preceded Sound	Session	Number of paired presentations	Conditioned reactions to light: Number	Conditioned reactions to light: % trials in which present
G	400σ	Day 1	29	20	69%
		Day 2	29	14	48%
D	300σ	Day 1	10	1	10%
		Day 2	17	4	24%
		Day 3	25	16	64%
		Day 4	16	9	75%
E	300σ	Day 1	24	1	4%
		Day 2	31	8	26%
F	250σ	Day 1	34	4	12%
		Day 2	35	3	9%
		Day 3	34	14	41%
		Day 4	33	18	55%
		Day 5	31	27	87%
		Day 6	12	9	75%
I	200σ	Day 1	31	12	40%
	250σ	Day 2	34	26	76%

modified by the presence of the light in those reactions in which the light stimulus preceded the sound.[11] The mean reaction-time of the conditioned responses to light varies from 207.9σ to 297.5σ under the diverse conditions of the different series. The latency

[11] For all the reactions of the eight subjects, the reflexes to sound had the following characteristics:

	Cases	Latency in sigma: Mean	Latency in sigma: S.D.	Extent in mm.: Mean	Extent in mm.: S.D.
Reactions to sound alone.....	448	39.9	8.1	12.8	11.6
Reactions to sound paired with light	1601	38.8	8.3	15.7	11.8

The latency of the reflexes to sound is close to the value of 39.4σ reported by Dodge (12).

to light is in every case less than the interval by which the sound stimulus followed the light stimulus; that is, the lid reaction to light, after conditioning has set in, begins for each of the five subjects before the sound stimulus occurs in the paired presentations, and the sound stimulus is followed by a reflex of normal latency. The mean reaction-times thus confirm the dual nature of the responses as pictured in the specimen records.

TABLE 3

Extent of Lid Closure to Light and Sound During Sessions with Five Subjects

Subject	Extent of Reactions to Sound in millimeters						Extent of Reactions to Light in millimeters					
	Sound alone			Light precedes			Light alone			Sound follows		
	n	Mean	S.D.	n	Mean	S.D.	n	Mean	S.D.	n	Mean	S.D.
G	10	17.5	6.9	24	7.8	4.4	5	19.0	14.8	33	9.3	14.3
D	19	10.4	9.8	40	7.8	6.9	10	5.0	5.9	26	8.2	5.9
E	27	28.9	9.1	45	21.1	5.3	5	17.0	8.9	6	15.0	11.1
F	36	11.4	5.6	104	12.4	7.5	14	3.1	1.8	75	3.3	1.9
I	16	32.0	6.1	27	34.2	3.5	4	10.8	8.4	31	6.4	6.9

When the reflex to sound continues a lid closure begun to light, the extent of closure to be attributed to the reflex to sound is not evident from the records, and such cases, because they are equivocal, are omitted from the summarized reactions to sound when light precedes. Equivocal cases are also omitted from the reactions to light when sound follows, accounting for the slight discrepancies in number of cases between Tables 3 and 4. A reaction-time may be unambiguous for a lid movement whose extent has been confused by further reactions during the course of closure.

TABLE 4

Reaction-Time to Light and Sound During Sessions with Five Subjects

Subject	Interval by which Light preceded Sound	Reaction-time to Sound in sigma						Reaction-time to Light in sigma					
		Sound alone			Light precedes			Light alone			Sound follows		
		n	Mean	S.D.	n	Mean	S.D.	n	Mean	S.D.	n	Mean	S.D.
G	400σ	10	28.0	3.0	24	30.3	7.3	5	221.5	67.8	34	210.7	52.4
D	300σ	19	48.8	8.9	40	46.6	7.7	10	231.5	53.8	30	242.2	39.2
E	300σ	27	40.5	7.2	45	38.8	6.9	5	297.5	65.4	9	276.2	44.2
F	250σ	36	42.1	4.9	104	40.3	6.6	14	235.8	43.0	75	209.7	20.0
I	200σ–250σ	16	32.6	4.0	27	34.8	4.2	4	219.5	43.5	38	207.9	30.0

V. The Minimum Latency of Conditioned Eyelid Reactions to Light

The conditioned reactions obtained from five subjects when the light preceded the sound by intervals of from 200σ to 400σ always appeared anticipatory to the unconditioned reflex to sound. In order to test the relationship of the reaction to light to the interval between light and sound, it was decided to successively shorten the interval, so that, if the reactions to light continued to be anticipatory to the sound, they would have successively shorter latencies. Subject D was used, from whom conditioned reactions had previously been obtained at an interval of 300σ between light and sound, as reported in Tables 1 to 4. The new series, which began over a month later, was started at an interval of 200σ between light and sound.

The first session consisted of reactions to light alone and to sound alone. Then followed five daily sessions in which light and sound were paired at the 200σ interval. Reactions to light alone were recorded at the beginning and end of each daily session, and reactions to sound alone were sampled from among the trials of the conditioning series.[12] There followed one session in which light alone and sound alone were presented without any paired stimuli. After the period in which no paired stimuli were presented, the interval between light and sound was reduced by 50σ, and a series of sessions held at the new interval. The intervals were reduced once a week during the four following weeks, until light and sound were being simultaneously presented. The use of one subject in this manner permitted a study of the modification in reaction-time of the conditioned responses to light, as the conditions became increasingly favorable for reactions of low latency.

The average latencies of reactions throughout the sessions are given in Table 5, and the frequency distributions are presented graphically in Figure 4. The time between the light and the

[12] See page 7 for the sequences of stimuli employed.

unconditioned reaction to sound is given, because this represents the training interval, that is, the time elapsing between the light stimulus and the reaction for which it was to become the substitute stimulus. This interval was decreased, under the conditions of the experiment, in the successive groups of sessions. The conditioned reactions to light are anticipatory to the unconditioned reaction at the 200σ interval, and at the 150σ interval, but a lower limit is reached for the latency of the reaction to light, and as the interval between light and sound is further decreased,

TABLE 5

The Latency of Conditioned Reactions to Light as Intervals Between Light and Sound Were Decreased in Successive Sessions with One Subject

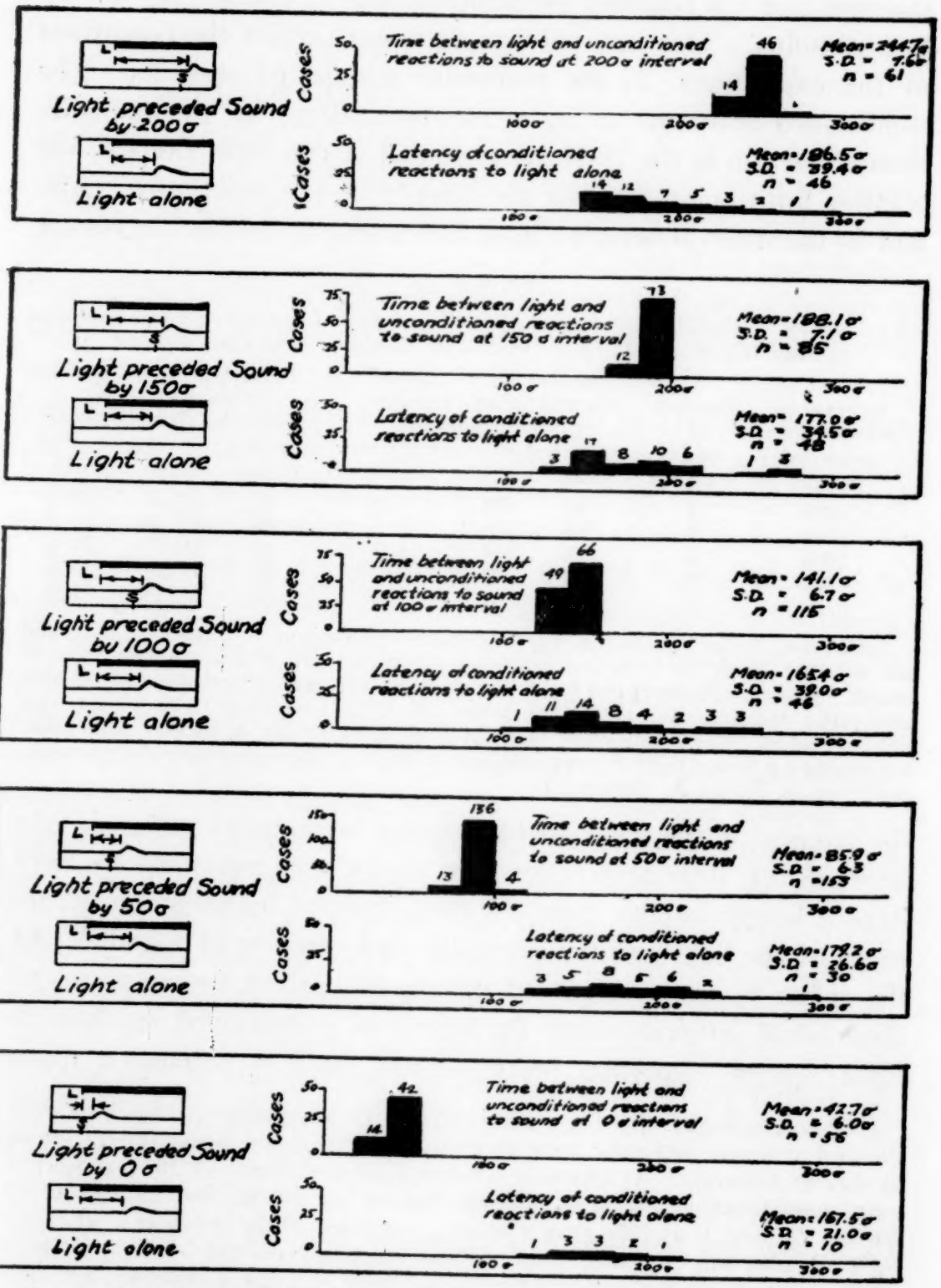
Interval by which Light preceded Sound	Number of daily sessions	Time between light and unconditioned reactions to sound in sigma			Latency of conditioned reactions to light presented alone in sigma		
		Cases	Mean	S.D.	Cases	Mean	S.D.
200σ	5	61	244.7	7.6	46	186.5	39.4
150σ	5	85	188.1	7.1	48	177.0	34.5
100σ	4	115	141.1	6.7	46	165.4	39.0
50σ	5	153	85.9	6.3	30	179.2	26.6
0σ	2	56	42.7	6.0	10	167.5	21.0

Ambiguous cases in which a reaction starts to light and is completed to sound are omitted from the reaction-times as given for unconditioned reactions to sound. The time between the light and the unconditioned reaction to sound was artificially reduced, by setting the sound stimulus to follow more closely the light stimulus. The conditioned reaction to light decreased in latency somewhat, but reached a lower limit for this subject at 165.4σ. The frequency distributions are given in Figure 4. Subject D.

the latency of the conditioned reaction is no more reduced. At intervals of 100σ and below, the conditioned reactions to light have a longer latency than the time interval between the occurrence of the light and the unconditioned reaction to sound.[13] As the reflex to sound occurred during the paired presentations at diminished intervals after the light, the conditioned reaction to light became somewhat more prompt, until it reached a mean

[13] This was found also for subjects F and G, who, after having been conditioned at longer intervals, were presented with light and sound stimuli paired at shorter intervals. At intervals between light and sound of 100σ, subject F gave conditioned reactions of average latency of 197.8σ, and subject G of 199.5σ. Subject F at 150σ gave reactions averaging 201.5σ in latency, when the light stimulus was presented alone. These reaction-times are lower than those of the reactions at the longer intervals for these subjects (Table 4), but they are greater than the training intervals between the light stimulus and the reflex to sound.

FIGURE 4. LATENCY OF CONDITIONED REACTIONS TO LIGHT WITH INTERVALS BETWEEN LIGHT AND SOUND DECREASED IN SUCCESSIVE SESSIONS WITH THE SAME SUBJECT



The reaction time of the unconditioned reactions to sound, as measured from the light stimulus which preceded, was reduced as the interval by which the light preceded the sound was successively decreased. The reduced time between the light stimulus and the occurrence of the eyelid reaction to sound is favorable for the formation of conditioned reactions of low latency. While the latency of the conditioned reactions decreased slightly as the intervals were shortened, a lower limit was reached for the mean latency at an interval of 100σ between the stimuli.

latency of 165.4σ. This was its lower limit; reduction of the time interval between the reflex to sound and the light stimulus during further presentations did not further decrease the latency of the conditioned reaction to light. This lower limit is within the range of voluntary reaction-times.

At the shorter time intervals the dual response to the paired stimuli, present at the 200σ interval, no longer occurred, and the presence of the conditioned component had to be inferred from the increased amplitude of response to the paired stimuli. Control

TABLE 6

Extent of Lid Closure to Light and Sound with Intervals Between Light and Sound Decreased in Successive Sessions with One Subject

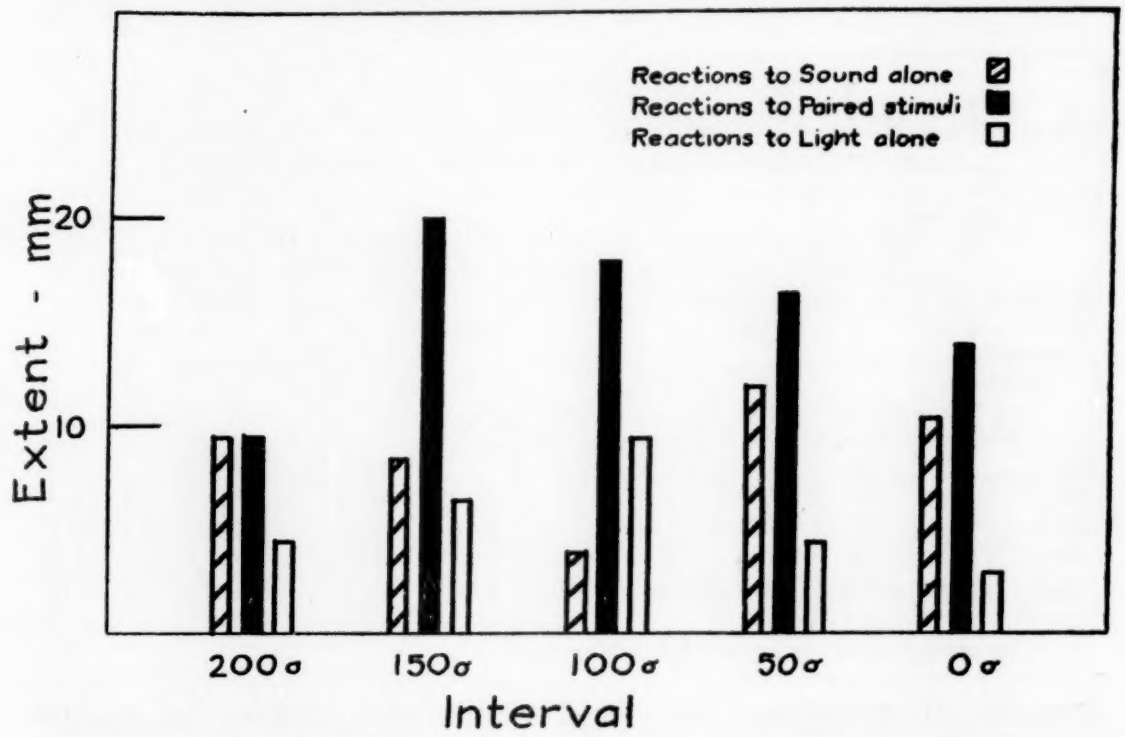
Interval by which Light preceded Sound	Extent of unconditioned reactions to sound alone —in mm.			Extent of reactions to sound when light preceded —in mm.			Extent of conditioned reactions to light alone —in mm.		
	Cases	Mean	S.D.	Cases	Mean	S.D.	Cases	Mean	S.D.
200 σ.....	26	9.5	7.8	61	9.5	6.8	46	4.5	6.4
150 σ.....	29	8.6	4.5	85	20.0	10.6	48	6.6	6.4
100 σ.....	29	4.1	2.9	115	18.0	13.2	46	9.4	9.7
50 σ.....	24	11.8	6.7	153	16.4	11.0	30	4.5	4.7
0 σ.....	10	10.5	7.8	56	14.0	11.5	10	3.1	3.6

The mean values are plotted in Figure 5.

records of responses to sound alone were taken by sample throughout the series. If the reactions to the paired stimuli were of greater amplitude than the reactions to sound alone, it may be argued that the increase in amplitude was due to the presence of the light stimulus. The amount of lid closure to sound alone, to sound with light present, and to light alone is given in Table 6, and the means are plotted in Figure 5. At the 200σ interval the dicrotic reaction occurred. The extent of the unconditioned reaction to sound is little affected by the conditioned reaction to light, and the control records to sound reveal reactions of an amplitude corresponding closely to the reactions to sound when light precedes. At shorter intervals between light and sound there is, however, an additive relationship between the reactions to light and sound, and the extent of the reaction to the paired

stimuli is seen to be something like a sum of the conditioned reaction to light and the unconditioned reaction to sound. The amount of increase in the reaction to the paired stimuli over the extent of reaction to sound alone serves as a rough measure of the degree to which conditioning has occurred. By this criterion,

FIGURE 5. MEAN EXTENT OF LID CLOSURE TO LIGHT AND SOUND WITH INTERVALS BETWEEN LIGHT AND SOUND DECREASED IN SUCCESSIVE SESSIONS WITH ONE SUBJECT



The three mean values presented for each interval are the reflexes to sound, the reactions to sound when light preceded but no reactions to it were distinguishable, and the conditioned reactions to light presented alone.

At the 200σ interval the dual reaction occurs, and the reflex to sound is not reinforced by the presence of light. At reduced intervals, the reaction to the paired stimuli is of greater amplitude than the reaction to sound alone.

The reflex to sound alone is a minimum when the conditioned reaction to light is a maximum, suggesting that when the sound is presented alone in the midst of continued reinforcement it is a less effective stimulus than without such reinforcement.

the lesser increase of reaction to the paired stimuli over the reaction to sound alone at intervals of 50σ and 0σ suggests that these intervals are unfavorable for conditioning. That they are unfavorable is further indicated by the falling off in amplitude of the conditioned responses to light alone. It may be noted that

contiguity in time is not a most favorable relationship for conditioning.

The conditioned response does not supplant the reflex to sound; it is an added reaction to light, which interacts with the reflex to sound as any second reaction closely related to the reflex in time of occurrence. A difference in nature between the new conditioned reaction and the reflex on which it was based was shown in a peculiar type of 'generalization' of the conditioned reaction. When the sound was presented alone in the midst of a series of paired stimuli, the sound replaced the light as the initial stimulus, and occasionally evoked the conditioned reaction usually made to the light, *i.e.*, the original unconditioned stimulus evoked the conditioned reaction. The reflex to sound always occurred, but it was followed on the record by a second component, distinguishable from the reflex by its longer latency. This second or 'conditioned' component did not make its appearance until the second week of conditioning, at the 150σ interval between light and sound, although records to sound alone had been secured throughout all of the sessions. It occurred spasmodically thereafter during the sessions at lesser intervals. The reactions to sound of Subject D showing two components had the following characteristics:

TABLE 7

The Two Component Reactions to Sound Presented Alone in the Midst of Conditioning Series

		Reaction-time to sound in sigma		Amplitude in mm.	
	Cases	Mean	S.D.	Mean	S.D.
Reflex component	27	36.1	3.9	4.6	5.7
Second component	27	150.4	30.0	17.6	13.0

The reaction-time of this second component is of the order of voluntary reactions to sound, and the records resemble those presented by Dodge for voluntary reactions to sound (10). The latency of this 'conditioned' reaction to sound is less than the latency of the conditioned reaction to light to which it corresponds. In traditional reaction-time experiments the responses to sound are of lower latency than responses to light.

In these experiments, the lower limit of the mean latency of

the conditioned reaction to light for any one set of sessions was 165.4σ, a reaction-time suggesting that of deliberate responses to light. In order to secure voluntary reaction-times in the same experimental situation for purposes of comparison with the latency of conditioned reactions, four of the same subjects were used, after participation in the experiment. Two of these (C and H) had participated without ever giving conditioned reactions. These served as controls for the other two subjects, whose voluntary reactions may have been altered by the presence of conditioning. Two forms of instructions were used during the series in which voluntary reactions were secured. In the first form the subject was instructed to wink as rapidly as possible after the light stimulus. These reactions appeared very much like the conditioned responses, except that they tended to be larger in amplitude. Under the second set of instructions, the subject was told to close his eyes to the light stimulus and to keep them closed. The complete closure showed that the instructions were being followed, and that the reaction was other than reflex. The first fourth of the trials were given under the first form of instructions, the two middle quarters under the second form, and the final quarter again under the original instructions. Controlled breathing was used as in the conditioning sessions, and served as a kind of ready signal. The results are found in Table 8.

TABLE 8

Reaction-Time of Voluntary Lid Responses to Light

	Reaction-time under instructions to wink to the light—sigma			Reaction-time under instructions to close the eyes—in sigma		
	Cases	Mean	S.D.	Cases	Mean	S.D.
Subjects without conditioned reactions (C, H).....	27	163.4	28.5	20	159.0	24.6
Subjects giving conditioned reactions (D, F).....	26	169.9	34.5	23	145.8	21.9
Average for 4 subjects.....	53	166.6	27.8	43	151.9	24.3

The voluntary reaction-time is comparable to that of the most rapid conditioned reactions. Closing the eyes is a reaction of shorter latency than winking for these subjects, although the difference is not reliable (Diff./S.D. diff.=2.8 S.D.).

The similarity of the voluntary reaction-times to the most rapid conditioned reactions is shown in Table 9. No special significance is to be attached to the practical identity of the values.

TABLE 9

Conditioned Reactions and Voluntary Reactions

	Reaction-time to Light		
	Cases	Mean	S.D.
Conditioned reactions in series of minimum latency (Subject D)	46	165.4σ	39.0σ
Voluntary winks to light (4 subjects)	53	166.6σ	27.8σ

The times are accurately measured, but the cases are few, and the variability large. That the conditioned reactions fall within the range of reaction-time to light is confirmed in the specific setting of the experiment.

VI. The Unconditioned Eyelid Response to the Light Stimulus

Reactions to light fall into two groups, a first reaction of mean latency of 110.7σ, present from the start, and the conditioned reaction of longer latency, present after stimulation by the paired light-sound combination. Frequency polygons showing the reaction-times of all responses to light obtained from eight sub-

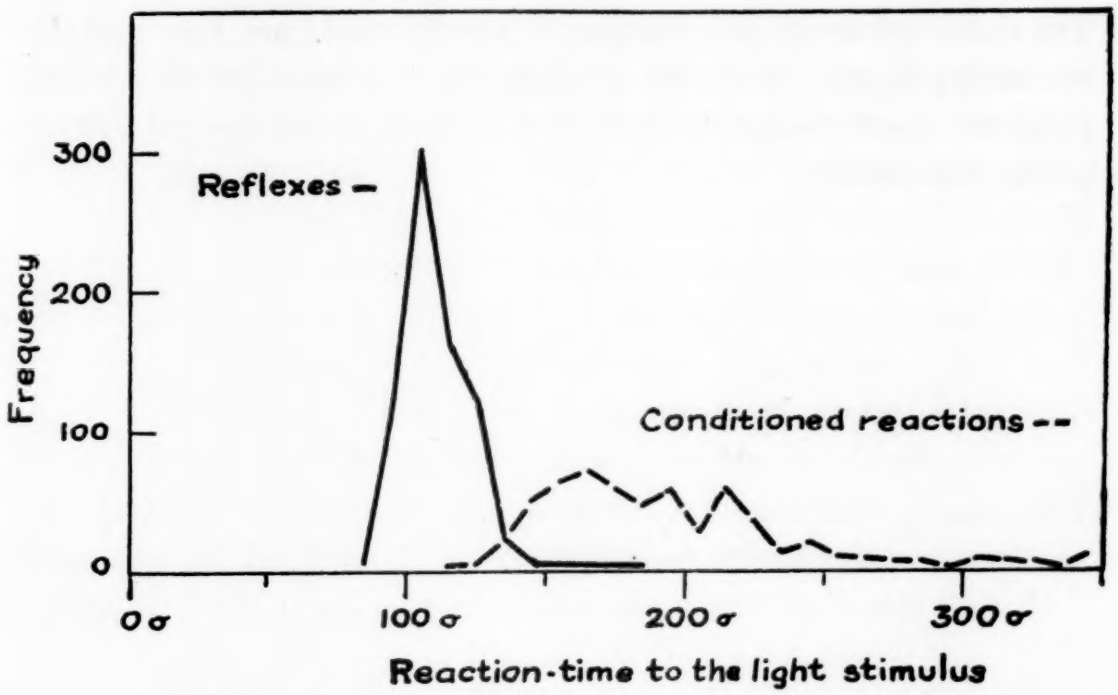


Figure 6. The Two Reactions to the Light Stimulus

The reaction of lower latency, termed the reflex, was occasionally present before, during, and after conditioning, independent of the presence or absence of the reaction of longer latency, termed the conditioned reaction. All eight subjects gave the reflex response more or less frequently; but five of the eight subjects gave conditioned reactions.

jects are given in Figure 6. Careful examination reveals a few ambiguous cases, but of the fact that there are two separable reaction types there is no doubt. The characteristics of both reactions are given in Table 10. The conditioned reaction has a greater average amplitude and a longer latency than the reflex. The first reaction is termed a reflex because of its presence before

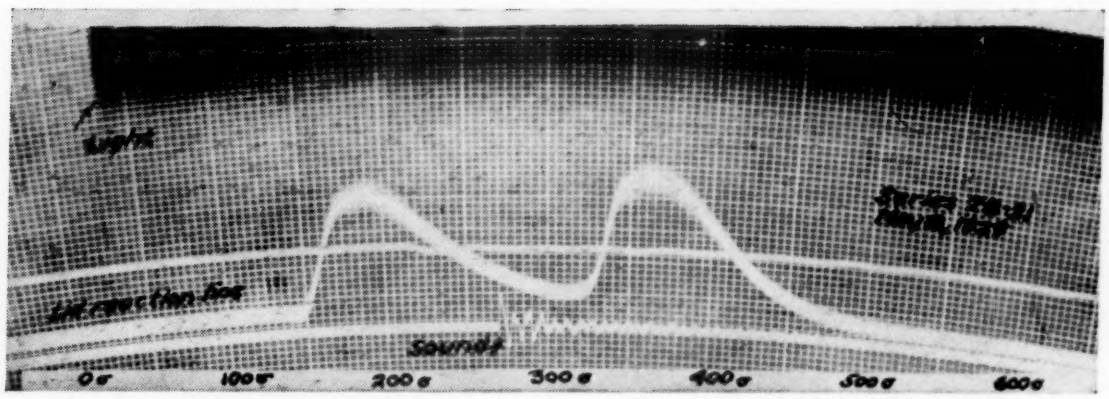


FIGURE 7. SPECIMEN RECORD OF REFLEX TO LIGHT AND REFLEX TO SOUND

The light preceded the sound by 240σ. The reflex response to the light (latency 110σ) is distinguishable from the reflex response to the sound (latency 40σ). Subject A.

conditioning, and its relatively slight variability subject to subject, although its time of reaction is longer than the latencies reported by other investigators for lid reflexes to light.[14]

TABLE 10

The Unconditioned Reflex to Light Compared with the Conditioned Reaction to Light

All reactions to light—8 subjects

	Cases	Mean	S.D.
Reaction-time to light			
Reflex	748	110.7σ	13.2σ
Conditioned reaction	688	195.2σ	42.5σ
Extent of lid closure			
Reflex	706	2.4 mm.	5.0 mm.
Conditioned reaction	497	6.9 mm.	8.1 mm.

The number of cases available for calculation is less for amplitude of response than for reaction-time because of occasional ambiguities when the reaction begins to light and is completed to sound. In such cases the reaction-time is clear, the extent of closure not clear.

For one subject (Subject A) the first reaction to light had an amplitude averaging 11.4 mm. for 10 reactions during the first session, before any paired stimuli were presented. The reaction may therefore be termed an unconditioned reflex to light. For this subject, the reflex to light was sustained at an average amplitude of from 5 to 10 mm. through repetition of paired light and sound stimuli, although when the light was successively presented alone, rapid decrement was shown. Intervals between light and sound ranged from simultaneity to 240σ. Longer intervals were not tried. At the 240σ interval other subjects gave conditioned reactions. Conditioning for this subject consisted in a reinforcement of the unconditioned reflex instead of the substitution of a new reaction, as for the other subjects. Subject A was used only during the earlier explorations, and the trials at any one time interval are too few to indicate the advantage of one interval over another. The curve of decrement when light was presented in isolation is given as Curve C of Figure 8. A corresponding decrement was not found when the sound regularly followed the light, although the component reactions were separable as in the specimen record of Figure 7.

[14] Zwaardemaker and Lans, 88σ (**50**); Dodge, 60σ (**9**). It must be kept in mind that they used much stronger lights.

The increase in amplitude of the unconditioned reflex to light due to the repeated presence of the sound is one form of resystematization which might be termed the conditioning of a reflex. The implications for the theory of conditioning of the two types of modified reactions to light which have been obtained (reactions of longer and shorter latency) will be considered later.

The unconditioned reflex to light was minimally evoked in all subjects, and could probably have been experimentally modified. That it was more difficult to modify than the reaction of longer latency is evident from the fact that it was not appreciably conditioned in 41 experimental sessions with seven subjects at intervals between the light and sound ranging from simultaneity to 150σ, presumably favorable for modifying the reflex. For these subjects, other than Subject A, the alterations in extent of the reflex response to light were slight, as shown by the frequency distribution of Table 11. Of 551 measurable reactions, 530 were

TABLE 11

Extent of Unconditioned Reflex to Light

7 subjects (not including Subject A)

Extent in mm.	Number of reactions
5–5.9	1
4–4.9	5
3–3.9	5
2–2.9	9
1–1.9	39
0–0.9	492
Total	551

below 2 mm. in amplitude, and but a single response reached an amplitude of 5 mm. While the responses of Subject A showed that the reflex to light may be modified by pairing the light stimulus with the sound stimulus, the reflex is not nearly as susceptible to conditioning as the reaction of longer latency, under the circumstances of these experiments.

For subjects who had been previously conditioned at longer time intervals, the presentation of paired stimuli at reduced intervals, instead of appreciably reinforcing the reflex to light, reinstated the conditioned reaction, even though its latency was longer than the interval by which the reflex to sound followed

the light in the new conditioning series. This has already been reported for Subjects D, F, and G, p. 19.

For subjects not previously conditioned, no conditioning was obtained at these reduced intervals, although the number of repetitions was too small for the assertion to be made that such conditioning was not possible.

VII. Decrement in Eyelid Reactions to Successively Repeated Single Stimuli

Reaction decrement following the successive repetition of an isolated stimulus has been known as negative adaptation. Pavlov uses the term 'experimental extinction' to describe the corresponding falling off in conditioned reflexes on successive presentations of the conditioned stimulus.[15] The three reactions with which this study has been concerned, the reflex to sound, the reflex to light, and the conditioned reaction to light, all show decrement upon the repetition of their respective stimuli. Curves of diminution in extent of response in consecutive trials are given in Figure 8.

A composite curve for the reflex to sound from 8 subjects (A, Figure 8) shows a downward trend in ten presentations of the sound alone. The high level is maintained because the most reactive subjects showed but slight diminution in that number of trials. A curve is also given for one subject (Subject D) for the average amplitude during four series in which the sound was presented alone (B, Figure 8). A rest of two minutes introduced after the sixth presentation shows as a recovery in both A and B. The use of frequent rest periods and of relatively short sessions obviated to some extent the decrement in reaction during the conditioning series. It was desirable to maintain the maximal reaction while attempting to establish a relationship between it and a new stimulus.

The unconditioned reflex to light was of sufficient amplitude to study statistically only in the reactions of Subject A. The extent of reaction fell off rapidly as the light stimulus was successively presented alone. A graph showing the course of decrement for ten presentations of the light at 30-second intervals is given as Curve C of Figure 8. Each point on the curve is an average of

[15] Winsor argues that Pavlov's term is appropriate for both phenomena, which are not two but one (47). So also Razran (36) and, with reservations as to their identity, Humphrey (24).

the reactions for that trial occurring in seven experimental periods.

Data are available for the conditioned reactions from six successive presentations of the light alone at the beginning and at the end of fourteen daily reconditioning series with Subject D.

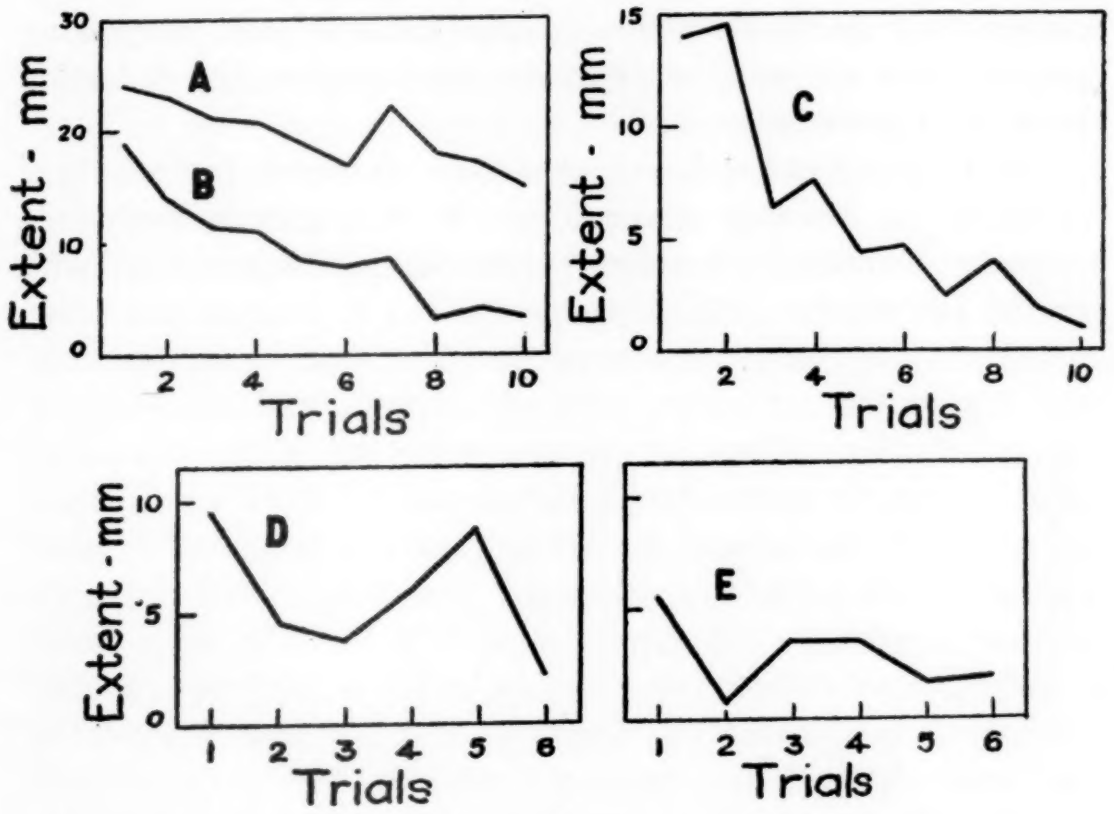


FIGURE 8. DECREMENT IN EYELID REACTIONS TO REPEATED SINGLE STIMULI

A and B. Reflex reactions to sound alone. Curve A represents an average for 25 sessions with 8 subjects for each of 10 consecutive trials at 30-second intervals. Curve B is drawn from the averages of four sessions with subject D. The rise after trial 6 represents recovery during a 2-minute rest period regularly introduced at that point.

C. Reflex reactions to light alone. Curve C represents the average extent of response for 7 sessions with subject A.

D and E. Conditioned reactions to light. The curves represent averages from 14 sessions with subject D. Curve D shows the average extent of response during six presentations of light alone at the end of the daily conditioning series. Curve E represents the extent of response to light alone during trials at the beginning of the daily conditioning periods.

After the daily conditioning session, the reaction was fairly well established, and the decrement within six trials at the end of the session was neither regular nor marked (D, Figure 8). The

conditioning lasted over until the following day, so that a curve can be constructed for the decrement within the first six trials of the day (E, Figure 8). The loss overnight is suggested by the mean amplitudes of response: 5.8 mm. for the trials at the end of the day, 2.8 mm. for the trials at the beginning of the following day. The first reaction of the day happens to be of greater extent than the last reaction of the previous day, suggesting recovery, but the irregularity of the curves makes any deduction from them precarious.

Reaction decrement has been shown to occur for all three reactions on repeated stimulation. It is a prevalent type of response modification resulting from repeated stimulation with similar stimuli.

VIII. Discussion and Interpretation

1. *Conditioned Reactions and Voluntary Reactions*

All the conditioned reactions obtained from five subjects, including those formed under conditions favorable to the development of reactions of low latency, fell within the range of latency of voluntary reactions. These findings agree with the results of previous experiment.[16]

That the conditioned reaction was not a deliberate voluntary wink is evidenced by (a) the reports of the subjects, (b) the rate and manner of appearance of the reactions, and (c) the failure to secure conditioning with the same subjects at unfavorable time intervals. While the good faith of the subjects may be trusted, the evidence from the records has the advantage of greater objectivity. Voluntary reactions would not have appeared day by day with gradually increasing frequency and gradually increasing *small* amplitudes, as in Figure 2, page 13. Furthermore, conditioned reactions failed to appear under repeated stimulation at unfavorable time intervals, although the instructions to the subject and other factors in the experiment which might have been conducive to voluntary winking remained the same. The absence under some conditions, and the gradual appearance under others, seem to me to be the best arguments for distinguishing between these reactions and deliberate winks pursuant to instructions.

The involuntary nature of the conditioned reaction is hardly justification for calling the reaction a reflex act. For example, responses in reaction-time experiments become, after training, relatively automatic.[17] Nevertheless, reactions which have been developed under instructions deliberately followed by the subject are usually distinguished from reflexes. The distinction between

[16] Hamel (19) and Humphrey (23) for the finger reaction; Schlosberg (37) for the knee-jerk. Cason (4) must be discounted, and Dodge (12) has not presented his data.

[17] James: "The reaction whose time is measured is, in short, a reflex action pure and simple, and not a psychic act" (26, p. 90).

the two types of response (*i.e.*, deliberate response which has become habitual, and reflex response) is not easy. Wiersma has pointed out that both types of act are subject to similar modifying influences (46). That there might be a close relationship between conditioned responses and the responses in reaction-time experiments is altogether plausible.

The present experimental situation may be examined from the point of view of a reaction-time experiment. A subject sees a light, and the light is followed by a sound to which he automatically winks. After a number of such presentations, the subject begins to wink slightly before the reflex to sound, and the reflex wink finds the lid already in motion. The controls which affect this anticipatory wink are the processes which are involved in the discrimination of environmental changes and time relationships. The light has come to serve as a signal that the sound and wink are to follow. The tendency to wink to the light becomes more regular until from an external point of view the subject seems to have acquired a set to wink to the light, which set is maintained as long as the sound follows. The reflex to sound is protective, and the anticipatory wink may be thought of as an avoidance reaction. This is in line with Hull's interpretation of the advantage to the organism of having the conditioned reaction precede the occurrence of the noxious stimulus (21). The anticipatory wink may also be considered as a suitable epicritic supplementation of the original protopractic (reflex) response, in the sense suggested by Dodge (13). When the sound is omitted, the set is disturbed, and the wink to light falters.

The difference between the conditioned reaction and the deliberate reaction may lie primarily in the nature of the neuromuscular accompaniments or set, and in the circumstances under which that set is produced.[18] Under instructions to wink as rapidly as possible, a reaction to light occurs at the first presentation of the stimulus, while under reflex conditions the reaction

[18] The conditioned wink to sound alone in the midst of a conditioning series (p. 23) is understandable if the set favors reaction to any sudden environmental change. The word 'set' has no explanatory value, but it at least indicates complex and widespread activity.

would not have occurred until the light and sound had been paired together many times. Subjects not previously conditioned have been instructed to wink slightly to a light preceding a sound stimulus. The dual reaction is found, reaction to light followed by reflex to sound, and the records cannot be distinguished from the corresponding records of conditioned reactions, except that under instructions subjects find it difficult to wink as slightly as they wink during a conditioning series. In the conditioning experiment the instructions are self-given through the repetition of stimuli. Verbal instructions may give more uniform control than paired stimuli. Where verbal instructions are not feasible, as with animals and infants, the paired stimuli method for producing reaction sets would be very useful indeed, even though conditioned reactions under such circumstances came to be largely identifiable with the responses of trained subjects in reaction-time experiments. The usefulness, as in discrimination experiments, does not depend on identifying the response as a reflex. For example, Wever, using the method for tonal discrimination in cats, says that the breathing fluctuations utilized are not true conditioned reactions (45). According to the present interpretation, his breathing reactions are as truly conditioned as the eyelid reactions of the present study. Neither resemble very closely the unconditioned reflexes on which they are based.

2. *Types of Conditioned Reaction*

The eyelid reaction is a response of striated muscle, over which the subject has some measure of deliberate control. That conditioned reactions of the eyelid may under certain circumstances be very similar to voluntary reactions is certainly no evidence that all conditioned reactions are of this type. It happens that the other conditioned responses for which latent times are available (finger withdrawal and knee-jerk) are likewise responses of striated muscle to which there is also voluntary innervation. Conditioning, if it is adaptive, may be expected to involve mechanisms already available; under other circumstances, other mechanisms may be used.

Conditioning has frequently been reported for activities involving smooth muscle and glandular responses which are not directly subject to voluntary control. Such for example are the pupillary reaction conditioned by Cason (3), and the galvanic phenomenon conditioned by Freeman (16). The absence of direct voluntary control over motor reactions in such cases does not mean that higher processes are not involved in discriminating and analyzing the environmental relationships which call forth the new reactions. Freeman found that the galvanic responses of his subjects were correlated with the expectancy of shock. Even though the effector studied is not under voluntary control, it is questionable to speak of the whole process as reflex, when efferent processes are mediated through central activity of great complexity. Thus the responses of grief may be involuntarily aroused by a letter received in the mail, but the stimulating situation involves many symbolic processes as the significance of the letter is grasped. Bodily changes, such as weeping, are released involuntarily, yet the reflex term loses somewhat in clarity if we are to consider the letter as a stimulus to these reflexes. There is no assurance, pending further investigation, that conditioning of smooth muscle and glandular responses follows the same rules as the conditioning of processes like the conditioned wink which have the temporal characteristics of habitual deliberate responses to stimuli.

While much conditioning undoubtedly involves higher processes in such a degree as to cast doubt upon the advisability of the reflex term to describe it, there is yet the possibility that some conditioned reactions are genuine conditioned reflexes. This is suggested by the occurrence in these experiments of the reflex to light, which for one subject at least was experimentally modified through pairing with the reflex to sound. Let us suppose the conditioning of this reflex to light to be generally possible, in the sense that the threshold might be lowered so that the light stimulus which elicited at first but a minimal response would now call forth an augmented reaction. The reaction was of such small amplitude at first that a less sensitive device would not have recorded its presence. The increased reaction to light, not previously of appreciable extent, might appropriately be called a

conditioned reflex.[19] Such implicit reaction tendencies are very widespread, and make possible the appearance of reactions remotely related to the stimulus. Thus bodily disturbances may occur under certain drugs consequent to usually inadequate stimuli; a very loud sound may produce a body start reaction which is much more pronounced than the slight lid movement which is the vestigial response to lesser sounds. If paired stimuli may alter the threshold for reflex response in such a way that an inadequate stimulus becomes adequate, this alteration may be called conditioning, but it is somewhat different from the types of conditioning previously discussed.

Experiment alone can determine how many different types of conditioning there are. The present experiments suggest at least two, as represented by the modified reflex to light and by the reaction of longer latency which has been designated the conditioned response. Reactions involving smooth muscles or glands as the chief effectors were not represented in the experiments. All types of conditioning have in common the development of reactions under circumstances of multiple stimulation, although their metrical aspects may be widely different. It is quite unlikely that all conditioned behavior has the unity to justify the exploitation of the conditioned reflex as an elementary concept.

3. *The Complexity of the Conditioning Process*

During the conditioning process, three general types of response modification appeared on the record, (1) reaction decrement after repeated isolated presentations of the stimuli, (2) augmentation of response during reactions to the paired stimuli, and (3) the appearance of conditioned reactions, themselves being modified by and modifying the other reactions present. Any diagrammatic simplification which makes of the conditioned response simply the old unconditioned reflex attached to a new stimulus does

[19] Cason was using a sound which just failed to produce a reflex as his conditioned stimulus, and his recording device demanded that the reaction be of large amplitude before it could be detected. It is possible that he had some genuine reflexes to sound among his hybrid conditioned reactions (4). These would then illustrate conditioning by augmentation of a response of reflex type minimally present to begin with, corresponding to the conditioning of the reflex to light.

violence to a process which involves numerous modifying factors. Apart from teleological considerations, there is little justification for referring to conditioning as stimulus substitution. The result is alteration and addition rather than substitution.

Razran has not been guilty of oversimplifying the alterations which occur during conditioning, but he insists in his theory of dominance in making the conditioned stimulus give up its own (less dominant) activities, and acquire the dominant activity (36). There is good evidence for it, in some cases, but I do not see that it applies to the eyelid reactions obtained in this study. The perceiving of the light and the reflex response continued, even though a new conditioned reaction was added. All such speculation seems at present to be more safely confined to designated sets of activity which have been thoroughly investigated experimentally.

The redintegrative aspect of the conditioned response has been discussed by Cason (6) and Hull (21). One might expect, on the principle of redintegration, that after a dual response frequently occurred to light followed by sound that such a dual response would occur to light alone. Such was not the case; the light was responded to singly by its own component of the dual response.

Theories emphasizing the adaptive nature of the grosser manifestations of the conditioned response[20] and physiological theories which attempt to account for the more intimate processes of inhibition and reinforcement and for the finer time relations between events, are on different levels of scientific interpretation. Whether every condition of response alteration has adaptive significance in a broad sense may be questioned. For example, studies of responses to multiple stimuli at short time intervals show that but slightly altered intervals may cause reinforcement to give way to inhibition.[21] Other characteristics, such as refractory phase, may be specific to certain response systems, and can

[20] Hull: ". . . as an automatic mechanism which mediates, blindly but beautifully, the adjustment of the organism to a complex environment" (21).

[21] Bowditch and Warren (2) and Yerkes (48, 49) for reflexes. The importance of time interval in its effect on voluntary reactions is reported by Todd (42) and Jenkins (27).

be revealed only by experiment. Limitation of present knowledge at all points with regard to the interrelationship of adjustment systems of a simplicity which permits of refined temporal measurement, demands extreme caution with regard to generalizations regarding physiological aspects of response modification.

4. *The Conditioned Reaction and Learning Theory*

The conditioned reaction has been accepted in psychology because of its relevance to habit formation and learning. There is the tempting possibility that conditioning is the basic method of habit formation. This would indeed seem to be the hope of the behavioristic tradition.[22] The quest for a unitary process around which to systematize learning theory is easily understood. It would be altogether desirable to have some such linkage between physiology and psychology, leaving to the physiologists the task of revealing the finer neuroanatomical aspects of conditioning, and making the task of psychology the reduction of complex forms of learning to their component conditioned reflexes. If any reaction which the organism can make may become attached to any stimulus to which the organism is sensitive and this attachment regularly follows the rules set down by the physiologists for the conditioned reflex, a systematic unity for learning theory can be achieved, resting on the findings of an established science. Thus Symonds has worked over the laws of learning on the basis of the results from Pavlov's laboratory (**39**).

It may be agreed that conditioning exemplifies involuntary habit formation but the question remains whether or not it is the simple prototype of all learning. In part, the answer depends on further experimentation.

Conditioning has been very little studied under the controls which have been developed in learning experiments, controls such as practice equilibration, or the standardization of units for the

[22] Watson: "When a complicated habit is completely analyzed, each unit of the habit is a conditioned reflex" (**44**, p. 166). Hunter: "The present chapter has not afforded an opportunity for a detailed presentation of the work upon conditioned reflexes. Had such an opportunity been available, the conclusion would have been suggested that all learning is fundamentally of the conditioned reflex type, and that the analysis of the mechanics of the learning process must be based upon detailed physiological experimentation" (**25**, p. 622).

construction of a curve of acquisition. The curve of learning has been the standard instrument employed for summarizing the study of learning of various types. It is rather interesting that conditioning should be so widely hailed as the basic learning method when it has so long resisted systematic treatment by the very instruments which have proved most useful to learning theory. The learning curves of Figures 2 and 3 indicate the possibility of constructing practice curves for the development of conditioned reactions, but the fact remains that there are but few such curves in the literature. Until more experimentation has been carried on in which conditioning is studied as a learning process, it is too early to theorize with any confidence about the place of the conditioned reaction in learning. At present we know much about learning a great many activities; we know little about learning conditioned reactions.

There are certain formal criticisms being made in the meantime against considering the conditioned reaction to be the unit of habit. These criticisms take different points of attack on different assumptions. (1) On the assumption that the conditioned response is truly reflex, it falls within the criticisms being levelled against the consideration of behavior as a concatenation of reflexes. (2) On the assumption of its being a more complex process, it may be thought of as a sample of learning but becomes too complex to serve as an explanation of learning. (3) If accepted as a typical process, it is subject to the same criticisms which are being directed against association as a learning principle. These three criticisms will be examined.

(1) *Attacks on the reflex theory.* By the reflex theory is meant the assumption that all behavior is organized out of the reflex responses which are present at birth or laid down in the nervous system through a process of maturation. The organization of behavior on this theory is through the processes of stimulus and response substitution.

Coghill, after correlated observations of the growth of the nervous system and of the behavior of salamanders, is impressed with the unity of behavior from the start. He says:

" There is no direct evidence for the hypothesis that behavior,

in so far as the form of the pattern is concerned, is simply a combination or coördination of reflexes. On the contrary, there is conclusive evidence of a dominant organic unity from the beginning" (**8**, p. 89).

The local reflexes are provided only after the integrity of the individual is established and to attempt to derive the total behavior from the individual reflexes is a reversal of the natural order. Coghill believes his work to be critical of the conditioned reflex as it has been exploited in psychology.

Lashley attacks the reflex theory on the basis of its assumptions of fixed neural pathways related to specific sensory end-organs and effectors. If the simplicity and purity of the reflex concept is to be preserved, reflexes should be understood in these terms, after the manner of the simplest reflexes of spinal animals. If the concept is used loosely, as by Pavlov, it at least means regularity of sequence between stimulus and response. But this very regularity is what is, according to Lashley, most difficult to harmonize with the problems of psychology.

"The distinguishing features of the reactions which we designate as 'behavior' in contradistinction to reflex is that they are not conditioned by the excitation of specific limited receptors or by stereotyped central mechanisms, but involve features of plasticity which have never been expressed in terms of the reflex theory and which imply, as we have seen, an independence of specifically differentiated conduction paths" (**30**, p. 164).

Apart from the neurophysiological considerations, the criticism is essentially an attack on the conception of stimulus which the reflex theory implies. In its purer forms, the reflex theory means by the stimulus a physical change impinging on specific sensory endings. The response will be appropriate to the stimulus only in so far as the specific reflex arcs are appropriate to it through native connection or conditioning. Lashley points out that much equivalence of stimuli is simply equivalence of patterns, or ratios of excitation, of which the most familiar example is visual perception of form regardless of the particular retinal cells affected, or which of the two retinas receives the impression. "To say that a specific habit has been formed for each of the

possible positions is preposterous for the pattern may be one never before experienced" (30, p. 158).

Dodge has recently described the learning of a relatively simple action pattern under experimental conditions and he discusses inadequacy of the conditioned reflex as explanatory in that situation. The experiment consisted in visual pursuit of an oscillating pendulum. Records of eye-movements show that the pendulum is reacted to directly in slight corrective movements but these movements are superimposed on a response to the total pattern of sine wave movement. The slight corrective movements might be accounted for on the basis of conditioned reflexes in response to successive positions of the pendulum but the pendular motion of the eyes cannot be considered as a reaction conditioned to any specific position of the pendulum (14).

If Pavlov and his followers were insistent on a strict interpretation of reflex action, these criticisms of the reflex theory would have to be examined in detail. The conception of conditioning is loose enough, however, to include reactions to patterns and to include behavior which is complex. Thus Pavlov in listing the stimuli to which conditioned reactions may be given includes: the appearance of a natural agency, the disappearance of such an agency, diminution in strength (if sufficiently rapid), trace left by the previous action of an agent, duration of time, internal changes in the organism (32, pp. 38ff). It is only occasionally that the attempt is carefully made to relate conditioned reflexes definitely to spinal reflexes.[23] If conditioning is broadly conceived and not limited to the conditioning of specific reflexes, it is subject to the succeeding criticisms.

(2) *The conditioned reaction an unsatisfactory unit for learning theory.* When the conditioned reaction is not limited to reflex behavior, its definition in terms of physiology becomes

[23] Borovski (1) mentions Sherrington a good deal, but apart from the exploitation of after-discharge and prepotency, leaves the distance rather wide between the spinal and the conditioned reflexes. The lack of *rapport* between reflex theory and conditioned reflexes also works the other way. Thus Fulton, writing on reflex action in the Sherrington tradition in 1926, finds it unnecessary to mention the contributions of the conditioned reflex studies to the field (17). Guthrie has recently reiterated the view that conditioning need not imply the reflex theory (18).

somewhat more difficult. If conditioning is to be the basic form of learning, it cannot be limited to reactions involving the cerebral cortex. If one were to accept Pavlov's view that the conditioned reflex always involves the cortex, lower animals, without a cortex, either could not learn, or would have to learn by a process other than conditioning. To delimit conditioning by reference to the physiology of the central nervous system is at present precarious. This difficulty has already been made apparent from the discussion of the possibility of various orders of conditioning not necessarily following the same laws and from the complexity of the serial changes throughout the conditioning experiment.

Whatever clarity the conditioning process has for learning theory arises not out of its physiological definiteness, but from the conceptual simplicity of the stimulus-response terminology, coupled with the principle of stimulus and response substitution. But even this clarity is misleading for conditioning need not consist in substituted responses in any very specific sense. The conditioned eyelid reactions as reported were indeed lid movements and in that sense equivalent to the original reflex reactions to sound. But the reactions were as much different as they were alike, if examined metrically rather than teleologically. The stimulus substitution concept does not have in it sufficient fertility to account for the response alterations which occur as conditioning goes on.

The complexity of the conditioning process has been in its favor for exploitation as a theory of learning for it is complex enough to apply very widely to problems of human behavior. It has found use in the description of abnormal behavior, emotional reactions and all manner of acquisition in which conscious recall of the circumstances of habit formation is at a minimum. That it has found such uses, that it is so flexible, does not necessarily argue for its fundamentality as a starting point in describing learning.

It may well be that conditioning as a process open to laboratory investigation can serve as a basis for prediction in learning even

though it is further reducible to a number of simpler processes. One of the most carefully considered treatments of the conditioned reflex as the basis for quantitative prediction in learning is that of Hull (22) in which he attempts to show how trial and error learning of a simple order may be derived from known facts about the conditioned reflex. His paper is a clear indication of the usefulness of the concept for expository purposes. An animal is presented with a problem to solve. There are three alternatives, one of which is appropriate. The animal having been previously conditioned to each of these alternatives has three possible reactions of varying potential strength. Hull shows very ingeniously how by reinforcement and extinction these three fluctuate in value during successive trials of the animal until only the appropriate reaction is made. The resulting curve of decreasing errors is a familiar learning curve. The expository value of the deduction is unquestioned. Its explanatory value depends upon the simple trial and error behavior as deduced being genuinely more complex than the processes whereby the original three conditioned reactions were formed. Until the deduction is framed in more concrete terms, this factor of novelty in the deduced behavior is by no means assured. If trial and error is involved at all in the formation of the three conditioned reactions in the animal's repertoire, the prediction is being made on the basis of facts obtained at the same level of difficulty. This would be directly analogous to the prediction of a given bit of learning from a curve constructed on the basis of experiments with equivalent material. If the conditioned reflex is as complex as the processes which it successfully explains, conditioning can hardly be accepted as a principle coming from physiology to serve as the foundation for psychological theory.

(3) *The conditioned response no advance over association.* The conditioned reaction is thought by some to be a direct physiological substitute for association. Thus Perrin and Klein: "As a result of these limitations of the older subjective explanation (association), many psychologists have either abandoned it or modified it in favor of the objective and more physiological

explanation. This is usually described as the *conditioned reflex* explanation" (33, p. 92).

This statement is somewhat unfair to the associationists of whom even the most subjective were always quite aware that association was not, strictly speaking, between ideas. Thus Titchener speaks of associative tendencies between psychoneural processes (41, p. 164). The physiological tradition dates from Hartley on and in many of its representatives it was not as atomistic as the conditioned reflex principle. In so far as conditioning is a physiological interpretation of association, it is subject to whatever criticisms may be made of association. Peterson in attacking association includes the conditioned reflex exponents in his criticism: "The modern conditioned reflex enthusiasts are still in very close agreement with the general position of David Hartley and James Mill" (35, p. 264). The criticism of association by the *Gestalt*-psychologists groups the conditioned reflex with association. Thus Köhler: ". . . it sounds a little nicer if we talk about conditioned reflexes instead of association. I do not find, however, that the first concept is clearer than the second" (29, p. 298).

It is not the place here to attempt an evaluation of association or to examine the criticisms in detail. Attention is called to the fact that conditioning and association have much in common. In its very objectivity, conditioned reflex analysis may be less searching than association. For example, the following rather objective description of a conditioned defence reaction to a noxious stimulus which previously gave visual cues:

"The retinal image of the threatening object when at a moderate distance will be sufficiently like that which is received when it is close enough to deliver the injurious stimulus to evoke the defence reaction (withdrawal, flight) early enough for the organism to escape injury altogether" (21, p. 500).

The assumption here of sufficient similarity between the images when close and when at a distance avoids the problem of what constitutes similarity. The problem of equivalences, whether of stimuli or of responses, may be the most baffling part of the

story—a part in which the associationist is likely to be more interested than the conditioned reflex advocate.[24]

Many of the problems common to association and to conditioning await experimental attack. Whether or not contiguity in time is a basic principle, for example, is not a matter for dispute but for investigation. Contiguity in time between the conditioned and unconditioned stimuli was not the optimum interval for the formation of conditioned eyelid reactions. To seek for contiguity in terms of continuing proprioceptive or other processes is to bend the facts to the theory. It is quite as important to note the anticipatory nature of the conditioned reaction which is made possible by a *disparity* in time between the conditioned and unconditioned stimuli.[25]

In view of the dearth of facts and the various attacks on conditioning as a basis for learning theory, it would seem best to postpone judgment with regard to the finality of conditioning as *the* method by which learning takes place. We have at present far better standardized methods of studying acquisition in learning, say nonsense syllables, than we have methods of investigating conditioned reactions. Until more is known about conditioning than about more common forms of learning, it may be better to think of conditioning as a special case of learning than to think of each example of learning as a special case of conditioning.

[24] Pavlov's use of the term 'analyzer' (32, p. 110) for the sense organ and portions of the central nervous system involved in discrimination sets aside some of the most perplexing physiological problems in order to preserve an apparent simplicity of stimulus and response interrelationship.

[25] Dodge has recognized the systematic importance of the anticipatory nature of many conditioned responses. "The process of conditioning can probably be reinterpreted, in part at least, in terms of more familiar psychophysiological principles as anticipatory reaction in which systematically related stimuli take the place of more adequate stimuli as conditions of reaction" (15).

IX. Summary

1. Conditioned eyelid reactions were obtained from five out of eight subjects after successive presentations of a light stimulus preceding a sound stimulus by 200σ to 400σ. The Dodge pendulum-photochronograph was used as the basic instrument for presenting the stimuli and for recording the stimuli and reactions photographically. The eyelid reaction was registered by the shadow of an artificial eyelash so that record was obtained of the course of lid motion both in terms of time and extent. The light stimulus evoked at the start only occasional minimal unconditioned reflexes of a latency lower than that of the conditioned responses which later developed. The conditioned reaction appeared during the series of paired light and sound presentations as the initial component of a dual or dicrotic response, anticipatory to the second component which was the unconditioned reflex to sound. The isolated presentation of the light after such a series elicited a wink homologous with the first component of the dual response. The latency of the conditioned reactions to light averaged 195.2σ in 688 reactions, as compared with a latency of 110.7σ in 748 of the minimal reflexes to light present before and during conditioning. The two reactions to light were distinguishable.

2. In a series favorable for the formation of reactions of low latency, the interval by which the light stimulus preceded the sound stimulus was reduced successively from 200σ to 0σ during periods with one subject. The minimum mean reaction-time was found to be 165.4σ, obtained in the reactions at the 100σ interval between light and sound. This latency is comparable to the reaction-times obtained in voluntary winking to light.

3. For one subject the unconditioned reflex to light was large enough in amplitude to show modification due to repeated presentation of the light stimulus paired with the sound stimulus. The

reflex was not easily modified for the other subjects, for all of whom it was minimally present more or less frequently.

4. Decrement was found in the reaction to sound after isolated presentations of the stimulus and for each of the reactions to light as the light stimulus was successively presented alone.

5. Because of the comparability of some conditioned reactions, particularly in latency, to reactions under voluntary instructions, it is suggested that the paired stimuli serve gradually and relatively automatically to induce a set to react which may be similar to that quickly induced in adult human subjects through verbal command. The paired stimuli method, where comparable to the reaction-time method, is especially useful for investigations in which the subjects cannot be controlled by verbal instructions.

6. The reaction of shorter latency to light, presumably of reflex nature, was subject to experimental modification. This suggested that in addition to the first type of conditioned reaction represented by the responses of longer latency, there might be a second type, represented by the conditioning of the reflex to light, characterized as a reduction of the threshold for reflex response to a stimulus to which the reflex response was already implicitly or minimally present. Responses in which elaboration of sensory data involves higher processes and in which effectors are not under voluntary control may represent a third type of conditioning.

7. The occurrence of response decrement and reinforcement, the appearance of conditioned reactions as added and altered rather than as substituted responses, all point to the physiological complexity of the conditioning process.

8. The limited experimentation on conditioning as a learning process and the theoretical objections which may be raised against considering the conditioned reaction to be the unit of habit, suggest that for the present it may be better to think of conditioning as a sample of learning rather than as the foundation for learning theory.

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